Superconducting Cavity Tuner Performance at CEBAF*

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Abstract

At the Continuous Electron Beam Accelerator Facility (CEBAF), a 4 GeV multipass CW electron beam is to be accelerated by 338 SRF, 5-cell niobium cavities operating at a resonant frequency of 1497 MHz. Eight cavities arranged as four pairs comprise a cryomodule, a cryogenically isolated linac subdivision. The frequency is controlled by a mechanical tuner attached to the first and fifth cell of the cavity which elastically deforms the cavity and thereby alters its resonant frequency. The tuner is driven by a stepper motor mounted external to the cryomodule that transfers torque through two rotary feedthroughs. A linear variable differential transducer (LVDT) mounted on the tuner monitors the displacement, and two limit switches interlock the movement beyond a 400 kHz bandwidth. Since the cavity has a loaded Q of $6.6 \cdot 10^6$, the control system must maintain the frequency of the cavity to within ±50 Hz of the drive frequency for efficient coupling. This requirement is somewhat difficult to achieve since the difference in thermal contractions of the cavity and the tuner creates a frequency hysteresis of approximately 10 kHz. The cavity is also subject to frequency shifts due to pressure fluctuations of the helium bath as well as radiation pressure. This requires that each cavity be characterized in terms of frequency change as a function of applied motor steps to allow proper tuning operations. This paper describes the electrical and mechanical performance of the cavity tuner during the commissioning and operation of the cryomodules manufactured to date.

I. INTRODUCTION

CEBAF's accelerating structure is a 5-cell niobium cavity of the Cornell type manufactured by Siemens. The operating specifications are as follows:

E_{acc}	> 5 MV/m	
Q_0	$> 2.4 \cdot 10^9$	
Frequency	1.497 GHz	
$Q_{ext,\,fpc}$	$6.6 \cdot 10^6$	(fundamental power coupler)
$Q_{ext,\,fp}$	$1.3 \cdot 10^{11}$	(field probe)

Prior to cavity-pair assembly, inelastic tuning is performed on the cells of the cavity to ensure a flat field profile to within ±2.5% cell to cell [1]. The tuning corrections required for each cell are determined by bead-pull and are made by axially deforming the cells. The cavities are chemically processed, assembled into pairs and tested in a vertical dewar at 2.0 K. After verification of the cavity performance, the pairs are built up into a cryomodule. The module is then delivered to the tunnel to await cooldown and subsequent commissioning to verify the cavity specifications as well as operational criteria such as cryostat static and dynamic heat loads, helium pressure sensitivity and cavity tuner performance.

II. ELASTIC CAVITY TUNING

As previously indicated, each cavity is inelastically tuned to ~1494.7 MHz so that, after cooldown, will shift to the operating frequency of 1497 MHz, ± 100 kHz. This frequency is maintained by *elastically* tuning the cavity by compressing it with the mechanical tuner (see figure 1). The tuner is attached to the first cell with a fixed cell holder, and to the fifth with a swivel cell holder. A rigid titanium rod connects the two holders at one end and a drive shaft assembly connects the two at the other end. Tuning is accomplished by translating rotational motion of the worm/wheel gear assembly into axial movement of the swivel cell holder.

The tuning range of the cavity is specified to be ± 200 kHz from the initial frequency after cooldown, which corresponds to an operating range of ±0.125 in. This travel is bounded by limit switches located at ±0.125 in. and by solid stops limiting movement to ±0.187 in., the latter to obviate travel into the inelastic region and over stressing the interconnecting bellows. During operations, the feedback control system measures the phase difference between the forward and transmitted power, calculates the tuning angle, and drives the tuner stepper motor. A resonant phase shift of 20° corresponds to a frequency shift of 41 Hz.

$$\Phi = \tan^{-1}\left[2Q_L\left(\frac{\Delta f}{f\mathrm{drive}}\right)\right]$$

where $\Delta f = f_{\mathrm{drive}} - f_{\mathrm{resonance}}$

A change in tuning angle will result from fluctuations in the cryomodule helium bath pressure where ±1 Torr results in a cavity frequency shift of 100 Hz. At the design accelerating gradient of 5 MV/m, the frequency shifts ~ 75 Hz due to radiation pressure.

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During cryomodule commissioning, each cavity is characterized in terms of its sensitivity to each of these conditions as well as the relationship to the tuner assembly attached to it.

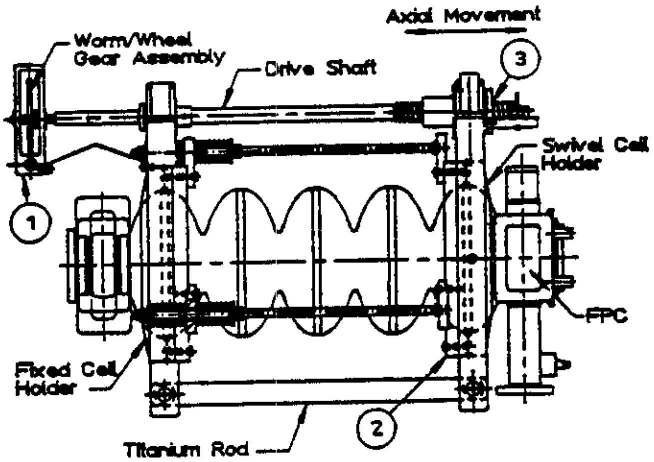

Figure 1. A cavity-tuner assembly depicting three sources of error (see text for explanation of each).

III. TUNER PROBLEMS AND SOLUTIONS

Ten tuners were delivered in early May 1990 to maintain a production schedule to supply 2 1/4 cryomodules for the injector section of the accelerator and the subsequent Front End Test. These tuners provided the initial evaluation of the design in an operational environment. The first and most serious problem was that some tuners would seize after cooldown. The problem was corrected by modifying a press-fit thrust bearing on the fixed cell holder to a slip-fit to mitigate binding due to thermal contractions. To allow operation of these tuners, a local stepper motor controller was connected that would "exercise" the assembly through the transitional temperatures. This method proved to be successful, but after two or three cooldowns it invariably fatigued the rotary feedthroughs causing catastrophic vacuum degradation, so it was quickly abandoned. A second concern was that the position of the limit switch, referenced to the cavity's axial movement of ±0.050 in., corresponded to less than half of the expected tuning range of ± 200 kHz. This was corrected by increasing the distance between the switch to more than twice that value, or ±0.125 in. The hard stops were also increased ± 62 mils beyond the control switch after it was verified that the new cold tuning range was still in the elastic region. The third concern was that the frequency after cooldown did not shift to the expected 1497 MHz, ± 100 kHz. In fact, results indicated that most were as much as 200 kHz lower than resonance which caused the LVDT to be out of range and useless. This problem was corrected by adjusting the warm frequency position from 1494.6 MHz to 1494.7 MHz. Recent performance data indicates that these were all successful design modifications.

IV. TUNER PERFORMANCE

The performance of the production-type cavity tuner is measured by phase-locking a self-excited loop oscillator to the cavity, tuning it to 1497 MHz and looping through a ±50 kHz span. Figure 2 is a typical hysteresis loop of the early production tuner.

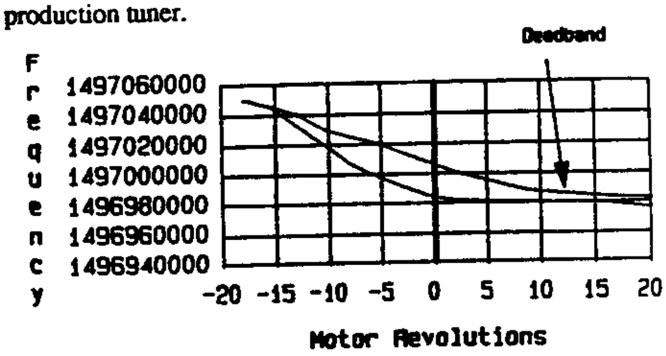

Figure 2. Typical hysteresis loop of CEBAF's early production tuner.

This curve depicts problems resulting from design flaws of three types (see Figure 1): 1) The backlash of stepper-motor-to-tuner gear slop. 2) The cell/cell holder mismatch due to inadequate allowances for thermal contractions. 3) The "deadband" caused by the failure to ensure that the cavity and tuner were adequately pre-stressed. The primary concern was the amount of hysteresis at resonance (mostly resulting from the cell/cell holder gap) of ±10 kHz related to about 10 motor revolutions. As stated previously, the control system is required to maintain the frequency to within ± 50 Hz of resonance and operates the tuner only when it falls outside this window to prevent excessive tuning. On the average, cavities were in need of adjustment about twice a day[2], indicating a worst-case motor operation of 20 revolutions. If the operational lifetime of the rotary feedthroughs meets the specified 50,000 revolutions[3], one might expect to repair a feedthrough every 7 years. This is less than the 10-year cryomodule removal/maintenance period. Obviously, the cell/cell holder fit was a critical issue to resolve.

Since the cavity and tuner assembly are subject to thermal contraction and the expansion coefficient of the aluminum cell holder is ~ 3 times that of the niobium cell, an unrealizable zero clearance leaves an inherent gap. Therefore, a region of hysteresis will always exist. For this reason the cell holders are manufactured as two half-cells matching the contours of the production cavity cells resulting in a very repeatable fit. In addition, a final shim adjustment is made during assembly. On average, only 10 mils or so has been the amount of shim required. The need for clearances in bearing and sub-assemblies has made it difficult to eliminate the "deadband" region, but if it is far enough away from the nominal required tuning range, it poses no problem. This was considered when the inelastic tuning frequency was increased by 100 kHz.

Figure 3 is a ±50 kHz hysteresis loop of a cavity-tuner assembly tested in the fall of 1992. The location of the deadband is approximately 30 kHz lower than resonance, which is the frequency after cooldown, and is largely narrowed. This is typical of the tuners presently installed after the aforementioned design and assembly modifications were incorporated.

Figure 4 depicts a ± 5 kHz hysteresis loop performed on the same tuner. Notice that the hysteresis region has been reduced to ± 1 kHz, corresponding to about a half of a motor revolution. This indicates a daily use of about one revolution which would increase the mean time between repairs to more than the 10-year cryomodule maintenance schedule.

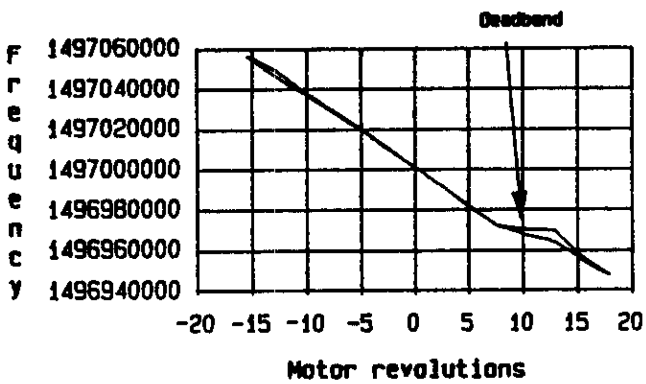

Figure 3. ±50 kHz hysteresis loop of a cavity-tuner assembly tested in the fall of 1992.

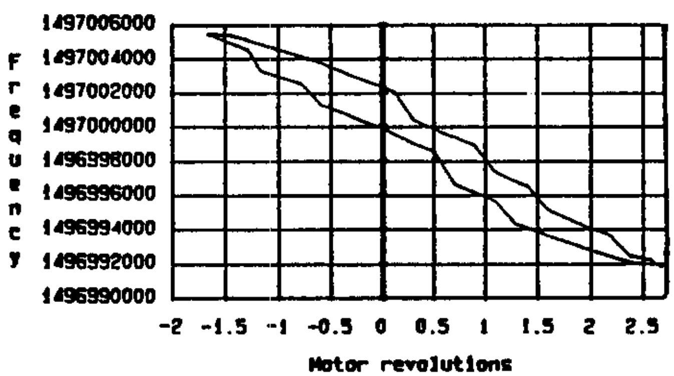

Figure 4. ±5 kHz hysteresis loop performed on the same tuner as in Figure 3.

V. CONCLUSION

The mechanical tuner used at CEBAF to maintain the resonant frequency of the SRF cavity has undergone a variety of design changes and assembly procedural modifications. These are the result of an ongoing initiative to improve the control capability as well as the lifetime expectations of this critical accelerator component.

VI. REFERENCES

[1] J. Mammosser, *et al.*, Analysis of Mechanical Fabrication Experience with CEBAF's Production SRF Cavities, *Proceedings of the 1993 Particle Accelerator Conference*, Washington DC.

[2] C. Hovater *et al.*, CEBAF Technical Note, TN#92-013, February 1992.

[3] A. Guerra, Jr., CEBAF internal document "Specification for Cryogenic Rotary Feedthroughs," 7/31/90.